Process Integration

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Module – 4
Targeting
Lecture - 11
Super Targeting- Optimization of Delta T min

Welcome to the lecture series on Process Integration. This is module-four, lecture number ten. The topic of the today's lecture is cost targeting for optimal delta T minimum. This process of cost targeting to find out of optimum delta T minimum is also called super targeting. We have seen that while solving a process of heating integration where a HEN has be to designed for a given duty, we have assumed some delta T minimum value, and then we have proceeded for the design. These assumptions of delta T minimum value was somewhat ad hoc in nature.

Though there are guidelines to find out the delta T minimum values for a given process or for some streams like liquid streams, gas streams or the steam or the cooling water, they are not very accurate. Now once we have ad-hoc selected delta T minimum value, we have to proof that this delta T minimum value is correct to some extent or we have to find out another value of delta T minimum, which is best suited for that situation. Now, this lecture tells you what is the best suited value which we call optimal delta T minimum value for a given network, and to find out optimal delta T minimum values will use the process of cost targeting to arrive at optimal delta T minimum value. This process is called super targeting.

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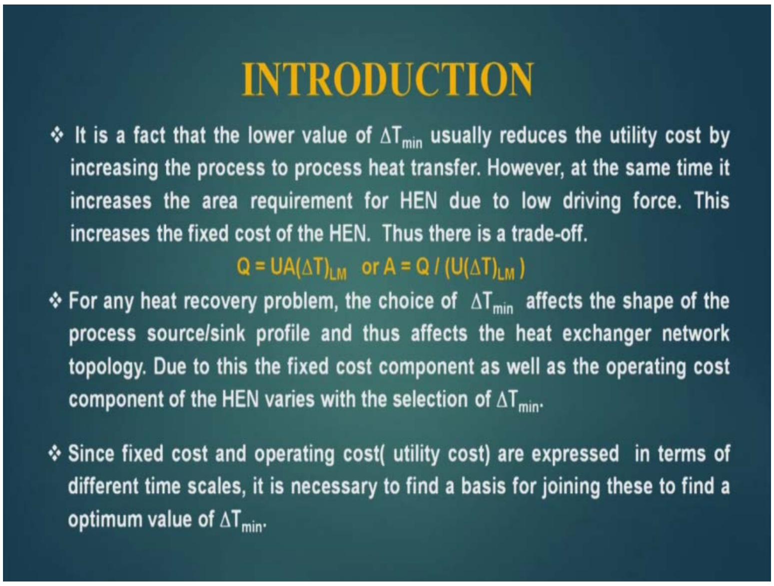

It is a fact that lower value of delta T minimum usually reduces the utility costs by increasing to process to process heat transfer. This is a well-known fact and that we have seen this in the energy targeting. However, at the same time, it increases the area requirement for HEN due to the low driving force. This increase in the fix cost of the heat exchanger network. Obviously, there is a trade-off between this that means when we are decreasing the delta T minimum, we are decreasing the utility cost, but at the same time, we are also increasing the fixed cost of the HEN. And hence there are two opposite forces, which are working when we change the value of the delta T minimum and thus calls for optimization. This can be known very easily from the equation that Q is equal to UA delta T LM or A is equal to Q divided by U delta T LM. If the log means temperature difference will decrease, the area will increase.

For any heat recovery problem, the choices of delta T minimum affects the shape of the process source and sink profiles and thus effects the heat exchanger networks topology. Due to this the fixed costs component as well as the operating cost component of the HEN varies with the selection of delta T minimum. It clearly tells that the delta T minimum affects the operating costs as well fixed costs. Since fixed cost and operating cost which is in this case utility cost, because we are not taking pumping cost into this are expressed in terms of different timescales, it is necessary to find out a basis for further joining these two to find out the optimum value of delta T minimum.

This clearly tells that when we are calculating fixed costs, the fixed cost is for the service period of the heat exchanger, while the operating cost are expressed in terms of in yearly basis. And hence the timescales are different and that is why to add them together, we have to change the fixed costs to annualized fixed cost, and then only we can add to the utility cost of the operating cost. Now this is required to find out the optimum value of delta T; that means, we will convert the cost data to TAC cost data that is total annual cost data. And then will plot this with delta T minimum to find out the optimal delta T minimum.

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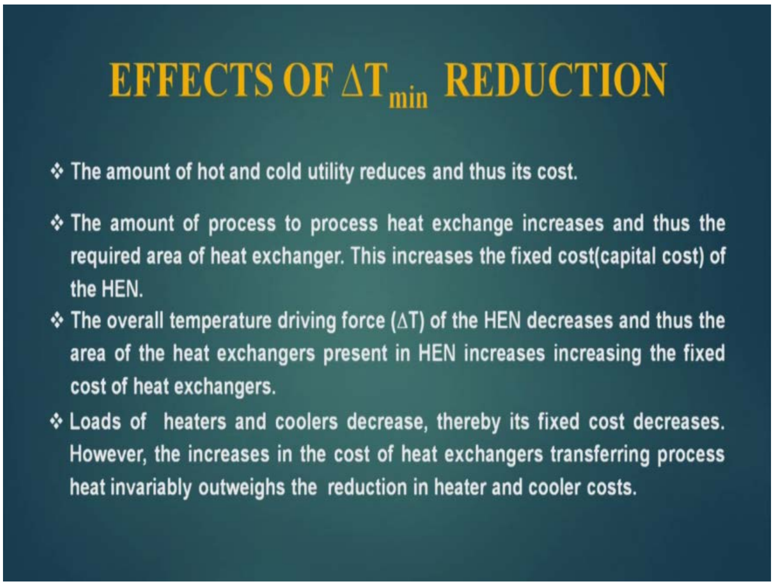

The amount of hot and cold utility reduces and thus its cost. When we are decreasing the the delta T minimum, so we are studying now the effect of delta T minimum reduction. What will happen, if I decrease delta T minimum. The first thing what we see is the amount of hot and cold utility reduces, and thus its cost also reduces - that means it will reduce the operating cost of the heater exchanger network. The amount of process to process heat exchange increases, when I decreased delta T minimum this happens the process to process of heat exchange increases and thus the required area of the heat exchangers. As the process-to-process heat exchangers increases to transfer this amount of heat, we have to increase the area of the heat exchangers; this increases the fixed cost that is capital cost of the HEN.

The third point is the overall temperature driving force delta T of the HEN decreases when we decrease the delta T minimum, and thus the area of the heat exchangers present in HEN increases increasing the fixed cost of the heat exchangers. This is a very well known fact if you decrease the driving force area requirement to pass a constant amount of heat will increase. Loads of heaters and coolers decrease, when I decrease that delta T minimum my amount of hot utility and cold utility decreases and hence the loads of heaters and coolers decrease, thereby its fixed cost also decreases. However, the increase in the cost of heat exchangers transferring process-to-process invariably outweighs the reduction in heaters and cooler costs.

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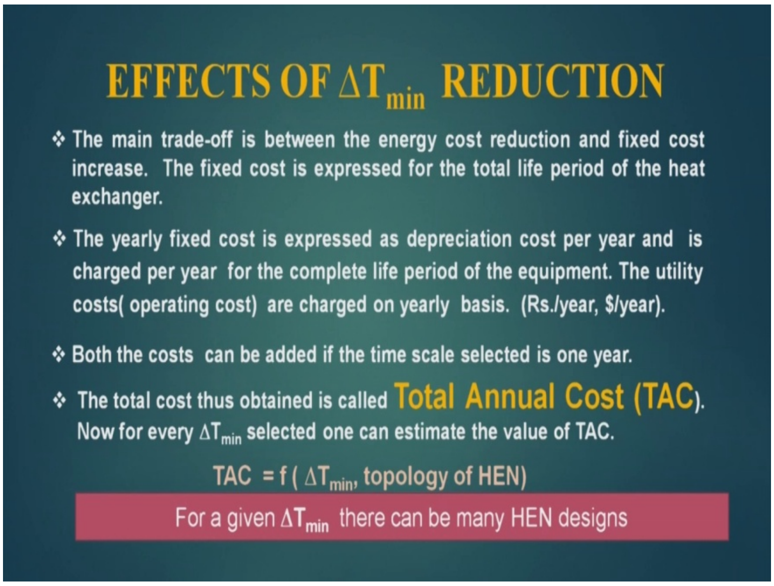

The main trade-off is between the energy cost reduction and fixed cost increase. So, when we decrease the delta T minimum, our energy cost reduces, but the fixed costs increases. So, there is a trade-off between this two fixed factors. The fixed cost is expressed for the total life period of the heat exchangers; this we all know. The yearly fixed cost is expressed as depreciation cost per year and is charged per year for the complete life period of the equipment. The utility cost that is operating cost are charged on a yearly basis. Both the costs can be added if the timescale selected is one-year. So, the total cost thus obtained is called total annual cost – TAC. Now for every delta T minimum selected one can estimate the value of TAC.

Once I selected delta T minimum, I can do the area targeting, I can do the energy targeting from area targeting, and I can find out the fixed cost and then convert the fixed cost to analyze fixed costs. And from the energy targeting, I can find out the hot utility and cold utility demand, convert them into the operating cost; add them together to find out the total annual cost. So, I can say that TAC is the function of delta T minimum and topology of the HEN. Why I am talking about topology, because for a delta T minimum for a given delta T minimum, we can design many heat exchangers networks, which can perform the job, but the cost of those heat exchangers networks will not be the same, but they will satisfy the requirement, and this heat exchangers will form different topologies of HEN. So, for a given delta t minimum, there can be many HEN designs and thus you can say that the TAC - that is total annual cost of heat exchanger network is a function of delta T minimum as well as topology of HEN.

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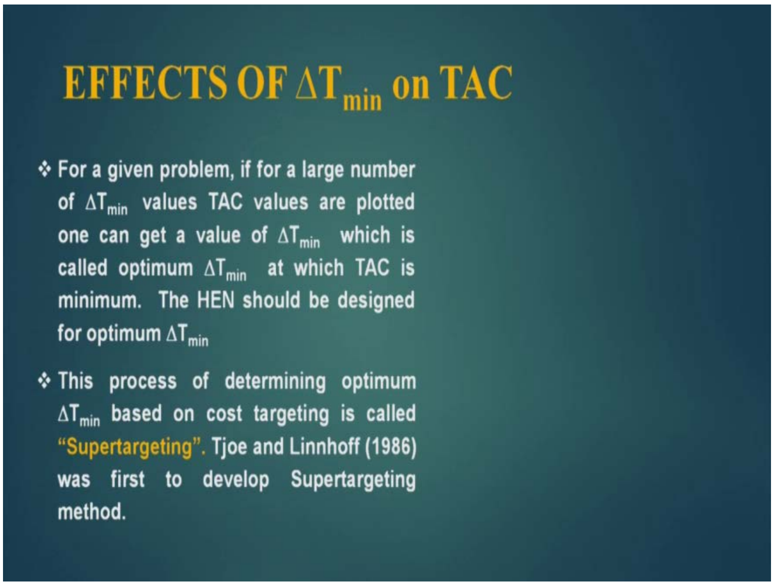

What are the effects of delta T minimum on TAC. For a given problem, if for a large number of delta T minimum values TAC values are plotted one can get a valley of delta T minimum which is called optimum delta T minimum at which the TAC is minimum. The HEN should be designed for optimum minimum value. So, if I am able to find out the delta T minimum optimum value, which means that if I operate my heat exchanger network at this optimum delta T minimum value then TAC of that heat exchanger network will be minimum. Now this is our aim, because we want to pass a certain amount of heat using a heat exchanger network at a minimum cost. If I am able to save cost, then it will be reflected in terms of my profit. So, the aim is to run a heat exchanger network which will require minimum cost.

This process of determining optimum delta T minimum based on cost targeting is called super targeting. Tjoe and Linnhoff in 1986 was first to develop super targeting method. Now this can be seen by a plot here which is plotted between TAC and delta T minimum. And the TAC of different heat exchangers networks, because when I am changing delta T minimum, the heat exchanger network is also changing; that means, I will have different heating exchangers networks for a given delta T minimum. And if I plot the TAC of those exchanger networks then I find a curve which resembles to this and this is the point where my TAC is minimum. So, this point of delta T minimum is called optimum delta T minimum.

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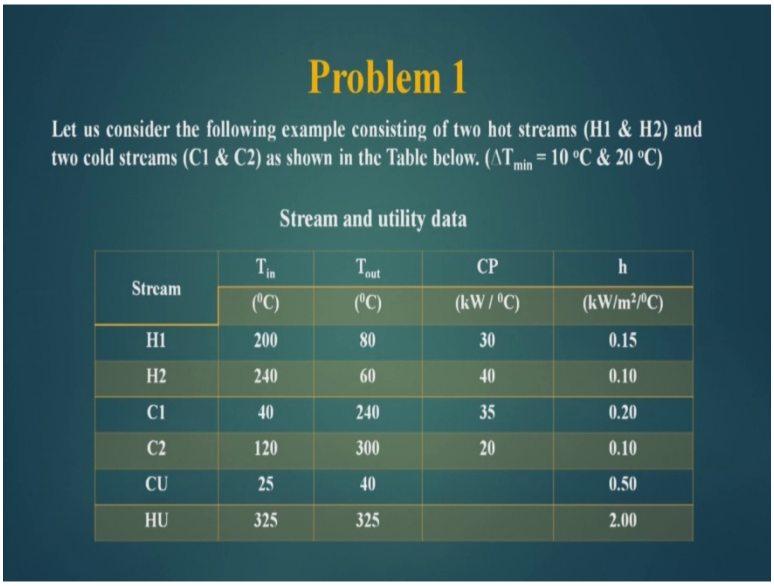

Now let us take an example to demonstrate this. Let us consider the following example consisting of two hot streams of H 1 and H 2, and two cold streams C 1 and C 2 as shown in the table below. Delta Team minimum is taken as 10 degree centigrade, and 20 degree centigrade. So, for 10 degree centigrade, I will first do the solve the problem and then for 20 degree centigrade, I will solve the problem and will see that what is the difference in delta T minimum solution at 10 degree centigrade and we service 20 degree centigrade. So, this is the stream data which is available for us the H 1, H 2, C 1, C 2, CU - that is cold utility, HU will be hot utility. Their supply temperature and target temperature are given, their CP values are given and their h values are given. The CP values of cold utility and the CP values of hot utility are given to us, because we have two find out this values by energy targeting.

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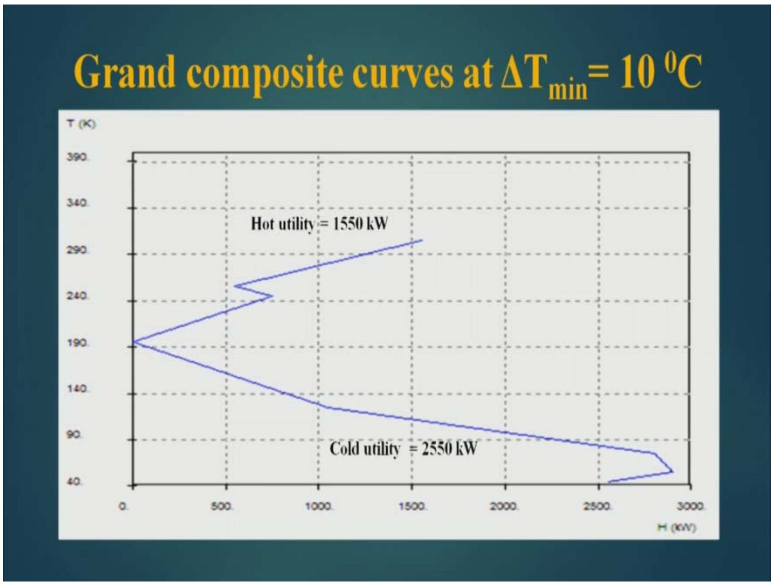

Now, if I plot the grand composite curve for this problem, the grand composite curve looks like this. Now here this is a pinch point, because this is shifted temperature. So, there will be a single pinch point here. The hot utility requirement for this problem is 1550 kilowatt, and the cold utility requirement for which is given by from this point to this point is 2550 kilowatt.

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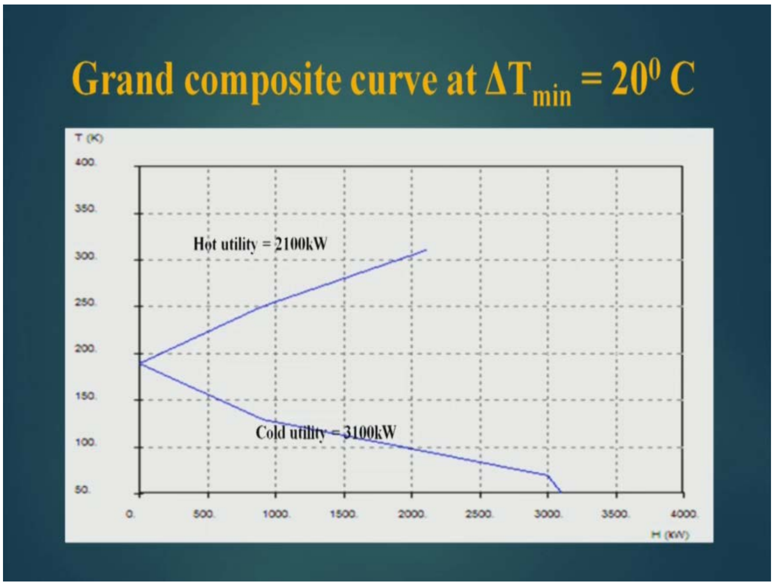

Now, if I plot it for delta T minimum equal to 20 degree, I clearly see that grand composite curve is changing. Here, the hot utility requirement is 2100 kilowatt, and cold utility requirement is 3100 kilowatt. I can show you the earlier one for a comparison, this is for delta T minimum 10 degree centigrade, and this is for the delta T minimum 20 degree centigrade.

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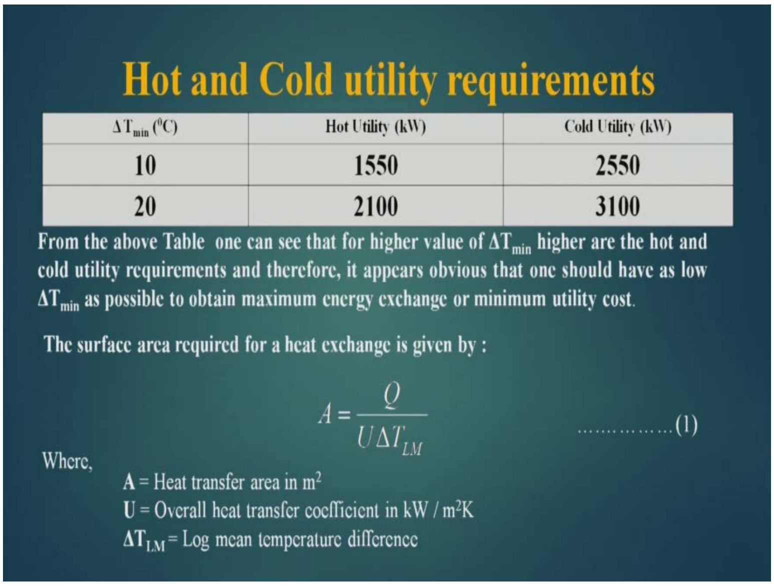

Now here we see, if we compare the delta T minimum values and the corresponding effect on hot utility demand and the cold utility demand, we clearly see that when delta T minimum is 10 degree centigrade, the hot utility demand is 1550. When it is 20 degree centigrade, this is 2100 kilowatt. So, the hot utility requirement has increased significantly, when I am increasing the delta T minimum. Similarly, for the cold utility requirement was 2550 kilowatt for delta T minimum equal to 10 degree centigrade, and it was 3100 for the delta T minimum equal to 20 degree centigrade. So, it has also increased significantly.

From the above table, one can see that the higher value of a delta T minimum higher are the hot and cold utility requirements and therefore, it appears obvious that one should have as low delta T minimum as possible to obtain maximum energy recovery or minimum utility cost. So, if you want minimum utility cost, I have to keep the delta T minimum as low as possible. However, there is the other side of it also. The surface area required for a heat exchanger is given by A is equal to Q divided by U delta T L M. Where, A is the heat transfer area in meter square; U - overall heat transfer coefficient, and delta T L M - log mean temperature difference, this is a very well-known equation for expression.

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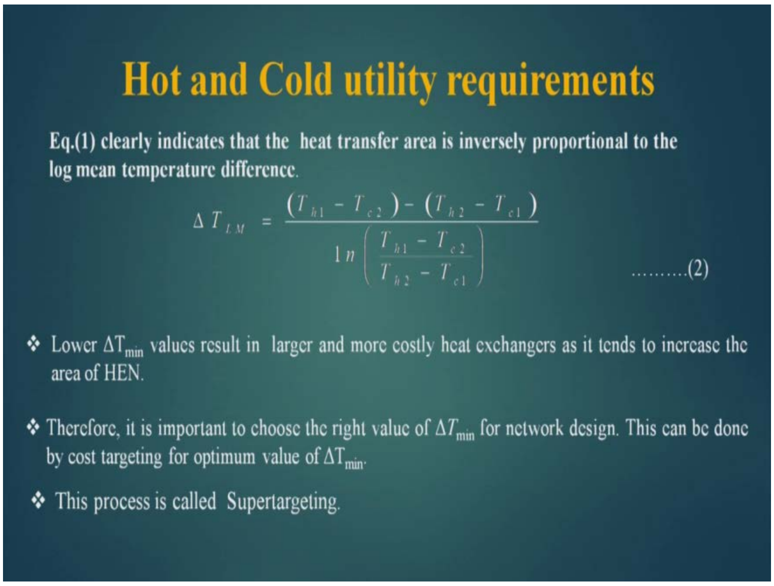

The log mean temperature difference can be computed using equation 2, which is also a well-known equation. So, I do not have to discuss it more. The lower delta T values result in larger and more costly heat exchangers as it tends to increase the area of heat exchangers. So, when I decreased the delta T minimum, the fixed cost of the heat exchanger network increases. So, there are two opposing effects, therefore, it is important to choose the right value of the delta T minimum for network design. This can be done by cost targeting for optimum value of delta T minimum. Now industry is run for profit making, so every decision is based on profit. So, here also the profit will be the last say and that is why we will select a delta T minimum or will compute a delta T minimum which will maximize our profit or minimize our operating cost. Now when we do this process is called super targeting.

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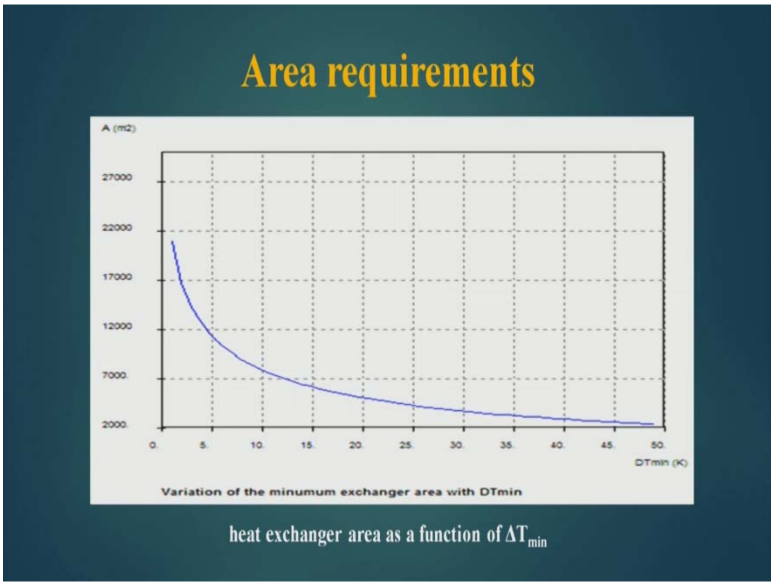

Now, if you see for the given problem what happens, when delta T minimum is increased. We see that when delta T minimum is low, the area is high. And when the delta T minimum increases, the area decreases; and then slowly it goes to touch the zero line, when delta T minimum will be maybe infinite. So, this is the decreasing area of the heat exchanger network. As the area will decrease, the fixed cost of the heat exchanger network will also decrease proportionally to the area, because we have seen that the cost law is a 1 plus b 1 like area to the power c 1.

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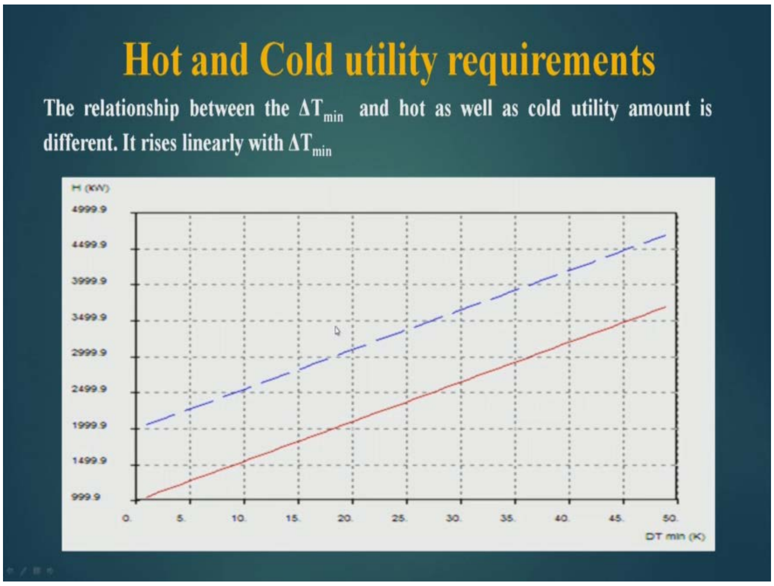

Now, when delta T minimum increases from here to here, the hot utility cost and the cold utility costs are increasing linearly. This is a linear increase, however, the fixed cost is not linear; it is a non-linear in nature, because the cost law is a 1 plus b 1 A to the power c 1 plus the relationship of the area and delta T minimum is also a non-linear relationship and cost law is also a non-linear relationship. Whereas, here I am finding that the hot utility and the cold utility increasingly linearly.

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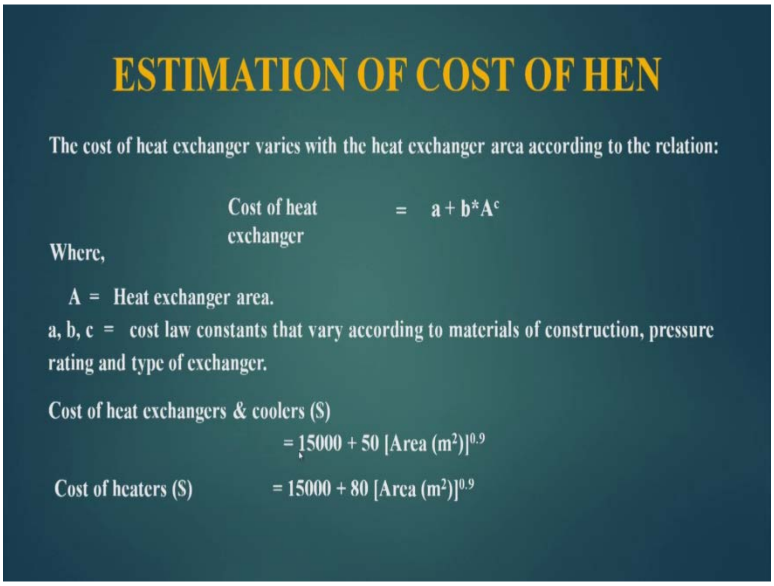

The cost of the exchanger varies with the heat exchanger area according to the relationship given below. Here we are using a plus b A to the power c. Where, a is the area of heat exchanger network, the cost of the heat exchangers and coolers are given like this. So, these are the cost formula, and here this is 15000 plus 50 area to the power of 0.9; and for the heaters, this is 15000 plus 80 area to the power 0.9, and this is for heat exchangers and coolers as well.

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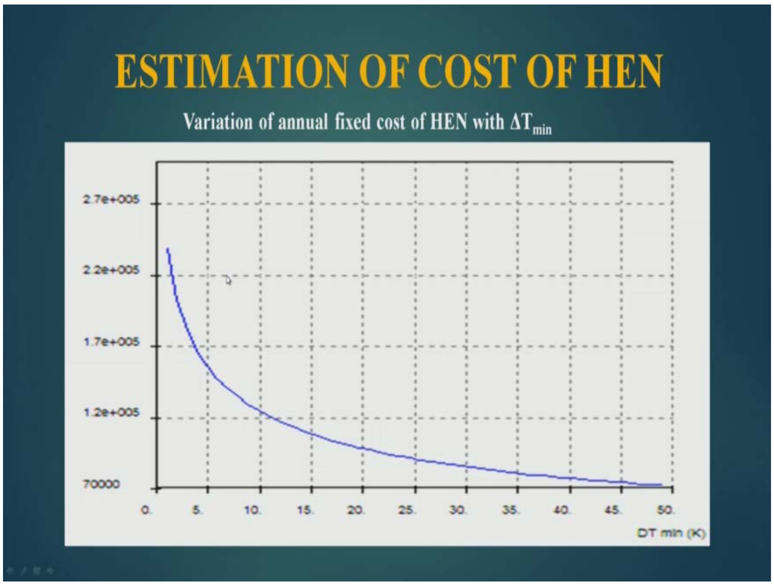

Now, this shows the variation of annual fixed cost of HEN with delta T minimum. Here we also see that this as a non-linear relationship and this was expected, because the areas changes in a non-linear fashion with delta T minimum and that the relationship between the area and the costs is also non-linear. So, we expect that there will be a non-linear relationship between the annual fixed costs and delta T minimum as well.

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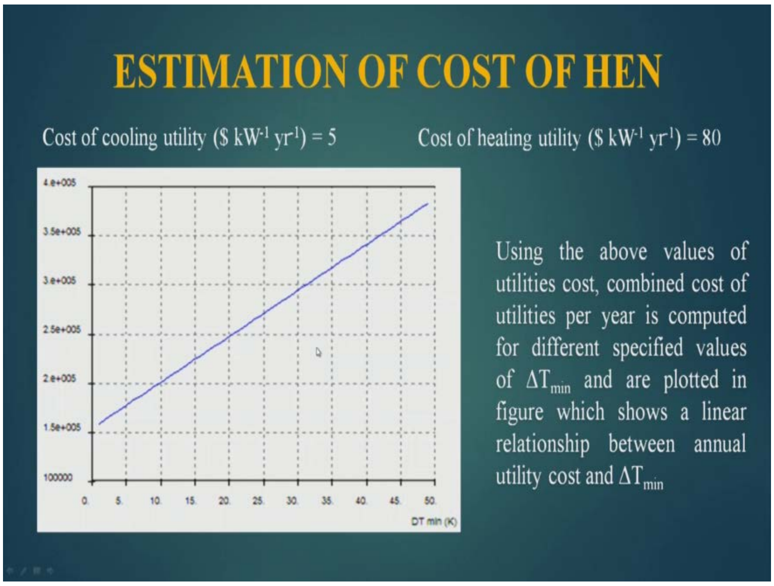

Now we take the cost of cooling utilities like this that is pi per kilowatt per year; cost of heating utility is 80 per kilowatt per year. And if you do so, when using the above values of the cost - utility cost, the combined cost of utilities per year is computed for different specified values of delta T minimum and are plotted in the figure which shows a linear relationship between annual utility cost and delta T minimum. This was expected because the relationship between delta T minimum, and the amount of utility was straight-line and we are the multiplying with its factors, so the relationship remains the same. So, we are getting a straight-line relationship between the cost of utility and the delta T minimum.

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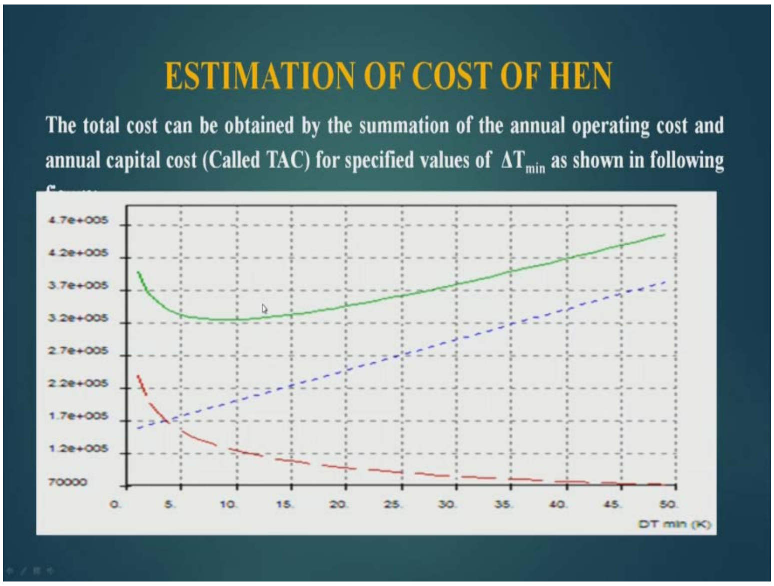

Now, the total cost can be obtained by summation of annual operating cost and annual capital cost, and this summation called TAC for specified values of delta T minimum as shown in the figure. Now this is the fixed cost which is decreasing, and this is non-linear in nature. This is operating cost, basically, the cost of utility, which is increasing in linear fashion. So, when delta T is increasing one this is increasing and this is decreasing. So, there are two opposite forces; one opposite to another, and hence a optima is expected in this case.

So, when we join these two that means this height plus this height with sum and put it here; this height plus this height, we sum and put it here. Like this, we will we sum this two this height plus this height we add and then put it here. If I do so, I get a curve like this, which is the summation of this two costs and this passes through a minimum point which is here. So, I can say that this is my delta T minimum optimum, but this is somewhat flat this is invariably, you get a flatter region where delta T minimum is optimum.

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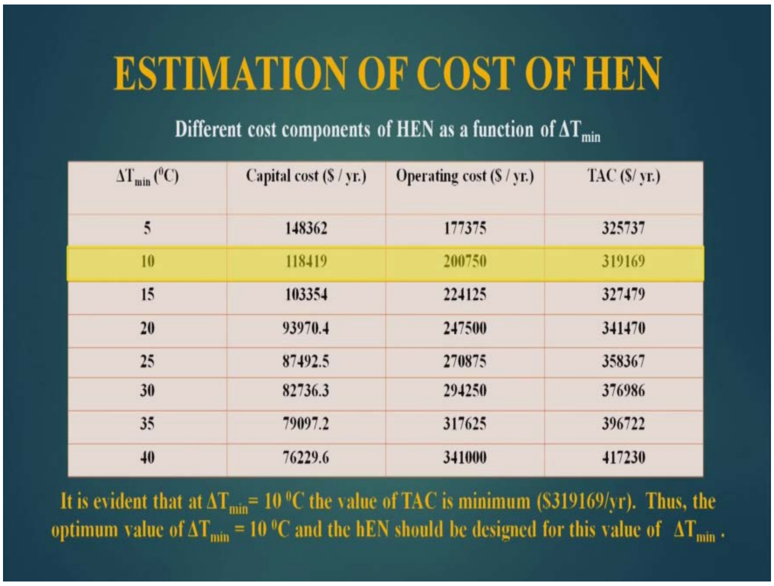
ESTIMATION OF COST OF HEN

Different cost components of HEN as a function of ΔT_{min}

ΔT_{min} (^{0}C)	Capital cost ($ / yr.)	Operating cost ($ / yr.)	TAC ($/ yr.)
5	148362	177375	325737
10	118419	200750	319169
15	103354	224125	327479
20	93970.4	247500	341470
25	87492.5	270875	358367
30	82736.3	294250	376986
35	79097.2	317625	396722
40	76229.6	341000	417230

It is evident that at ΔT_{min}= 10 ^{0}C the value of TAC is minimum ($319169/yr). Thus, the optimum value of ΔT_{min} = 10 ^{0}C and the hEN should be designed for this value of ΔT_{min} .

So, if I convert this into a table then for delta T minimum equal to 5, the capital cost is 148362, the operating cost is 177375, and the total cost is 325737. When I change this to 10, it becomes the capital cost is 118419, the operating cost is 200750, and the TAC is 319169. And when I go for 15 degree, the capital cost decreases less that is 103354; and the operating increase is more, it is 224125, and the over is 327479. So, what we see that if I am near my temperature 10, then the TAC of the heat exchanger network will be lowest and if I increase the delta T minimum more than ten, it is cost TAC is increasing. As the operating cost is far more than the capital cost, so obviously, the optimization the delta T minimum goes towards the lower operating cost that is why you get the value 10 degree centigrade here.

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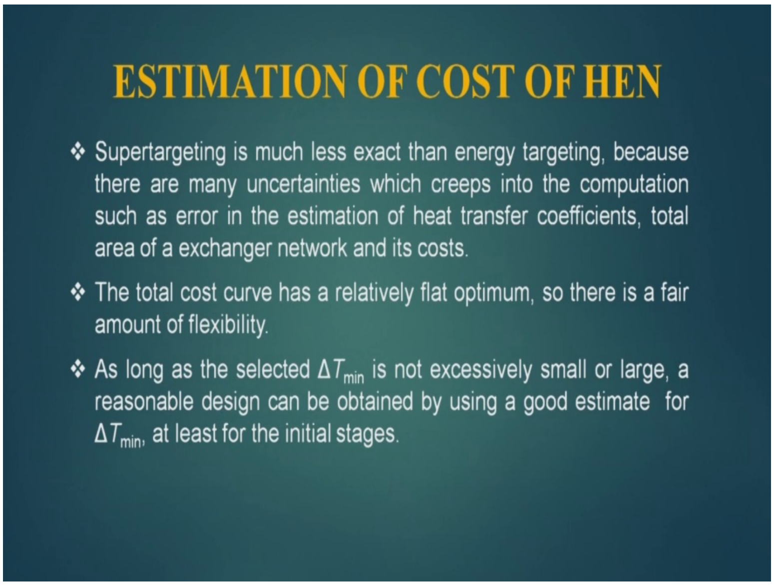

Super targeting is much less exact than energy targeting, because there are many uncertainties which creep into the computation such as error in the estimation of heat transfer coefficients, total area of heat exchanger network and its. We have seen that the computation of heat exchangers network cost depends upon so many things. And one of the important aspect is a heat transfer coefficient. Now we have also seen that if the heat transfer coefficients are different of the order of magnitude in a heat exchanger network, then the minimum area which is computed using area network area targeting is not very accurate. So obviously, these inaccuracies will creep into the super targeting also.

The total cost curve that is TAC curve has a relatively flat optimum, this we have seen this has got a flat optimum, so there is a fair amount of flexibility. So, you have a flexibility, you do not need a razor sharp optimum delta T minimum. If it shifts a little bit even then there will be very less loss, because the optimum area is flat, and that is why there is a flexibility in selection of delta T minimum optimum. As long as the selected delta T minimum is not excessively small or large, a reasonable design can be opted into by using a good estimate for delta T minimum at least for the initial stage.

Thank you.